acerosa and *continens*, as, without breaking the outer chamber of every shell, the difference could not often be determined.

Note.—From the latitudes and longitudes given above, the ship's course can be readily laid down on a map; and a more graphic representation will thus be obtained of the distribution of the minute ocean-fauna than can be conveyed in words.

DESCRIPTION OF PLATE V.

Fig. 1. *Globigerina* (*Orbulina*) *universa.*
2. *G.* (*Orbulina*) *acerosa*, n. sp.
3. *G.* (*Orbulina*) *continens*, n. sp.
4. *G.* (*Orbulina*) *continens* broken through the internal chambers.
5. *G. hirsuta.*
6. *G. bulloides.* Form No. 1.
7. *G. bulloides.* Form No. 2.
8. *G. bulloides.* Form No. 2: reverse side of Fig. 7.
9. *G. bulloides.* Form No. 3.
10, 11. *G. bulloides.* Other varieties.
12. *G. bulloides.* Reverse side of Fig. 11.
13. *G. inflata.* A sinistral shell.
14. *G. inflata.* A dextral shell.
15. *G. inflata.* Upper surface of a sinistral shell.
16. *Pulvinulina Menardii.*
17. *P. Micheliniana.*
18. *P. crassa.* A dextral shell.
19. *P. crassa.* A sinistral shell.
20, 21. *P. canariensis.*

On the Otolites of Fish, and their value as a test in verifying recent and fossil Species. By E. T. Higgins, Esq., M.R.C.S. &c. (Communicated by G. Busk, Esq., Sec.L.S.)

[Read May 3, 1866.]

The object of this paper is an attempt to show that the otolites of fish have a certain distinctive value in determining the genera and species to which they belong, and that the close study of them in the recent forms will enable the ichthyologist to confirm or disprove the specific relationship of recent individuals, and the geologist to determine the affinity of the fossil species. In making this attempt, it will be necessary to state my belief to what extent fish possess the faculty of hearing, and, in doing so, to indicate the

various modifications of the auditory apparatus of other members of the animal kingdom for comparison. The auditory organs consist of a contained fluid and of a solid body or bodies, with which the fibrillæ of the acoustic nerve are in close communication; but in order to render this simple form available for the recognition of delicate modulations, and give judgment of the distance and position of the vibration, a more complicated apparatus is given to the higher orders of the Vertebrata. We find in the Reptilia a drum or tympanum to receive the vibrations and transmit them, by means of an ossicle called the columnella, to the internal ear; a canal bent upon itself also makes its appearance, which may be looked upon as a rudimentary cochlea. A similar, though slightly modified, arrangement exists in birds. In Mammalia, in whom the powers of hearing are more acute, and whose power of appreciating modulations is more sensitive, we have an acoustic instrument of the most perfect description, consisting of a chain of four ossicles, a well-developed cochlea, tympanum, and external ear. By many naturalists the circular arrangement of feathers surrounding the external opening of the ear in some birds has been looked on as the equivalent of the external ear in Mammalia; it must, however, be but an imperfect representative.

As, however, sonorous vibrations communicated to water pass through it with great intensity, it is absolutely necessary that a considerable modification of the auditory organs of its inhabitants should exist, or they would be perpetually liable to injury, or even death, from the violence of vibratory shock; we therefore find, as might be anticipated, a much simpler form of auditory apparatus in fish, deprived of external ear, tympanum, and cochlea, though it has been stated that a rudimentary cochlea does exist in some fish. This rudimentary form will at once suggest that fish derive their sense of hearing from other sensations than such as we term *sound*, and receive over the whole surface of the body vibrations which are conveyed to the internal ear. That a fish does not possess hearing in any other than a very simple degree is capable of proof; and we have frequent and direct evidence that they have no sense of either the direction or the immediate vicinity or distance of the source of the vibrations which disturb them. The experience of fishermen confirms this. A shoal of fish taking the bait freely will be disturbed, and sink at once to the bottom of the water, on the rounding of a point by a steamer, though at an immense distance, with as much alarm as if the danger threatening them were in the immediate neighbourhood. With-

out for an instant doubting that fish possess, in an exquisite degree, the sense of hearing, *i. e.* of receiving the vibrations conveyed through the water, I must differ in opinion from Pliny and all subsequent writers who speak of fish "coming when they are called," of their being "assembled by means of music or of a whistle," for one reason: "Sonorous vibrations taking place in the air are with difficulty communicated to the water, unless a membrane be interposed." And yet, in the above-cited cases no artificial tympanum having been interposed, we are called upon to believe that fish perceive and recognize the various modulations of sound taking place in the air. May we not rather explain their assembling at any one spot by the vibrations communicated through the earth to the water giving them notice of the approach of some person to the spot where they are accustomed to be fed? It is a fact well known to all observant anglers, that, provided they keep out of sight and remain still, all the talking, whistling, and shouting will not disturb the fish one hundredth part as much as one stamp of the foot or sight of the person.

There exists considerable modification in the form of the auditory apparatus in the various families of fish; and the passage from the "single tubiform labyrinth of the Myxine," through the "*two* semicircular canals and vestibule of the Lamprey," into the *three* semicircular canals and vestibule of the higher cartilaginous and the whole of the osseous fishes is very simple.

The vestibule has been described as "dilating into one or more sacculi, separated from the *alveus communis* by a constriction or narrow canal." This description may apply to a few fish; but in by far the larger number no such separation exists. I shall therefore speak of the whole as the vestibule or vestibular sac, connected by one, two, three, or more tubular prolongations with the semicircular canals, the whole being filled with a thick mucilaginous or oleaginous fluid called endolymph, and surrounded by a thinner fluid, perilymph. "The semicircular canals are anterior, posterior, and external," and, though of large size, are considerably smaller than the passages traversed by them, and are suspended in them by a delicate network of fine threads of cellular membrane, no doubt for the purpose of softening the shocks received through the walls of the skull.

"In the higher Plagiostomata (Sharks and Rays) and in the Sturgeon, and also in the Lepidosiren, the whole are imbedded in the walls of the cranium," whilst in the osseous fish these internal parts of the auditory apparatus are lodged in a depression of the

skull on either side of the brain, to which Professor Owen has given the name of *otocrane*, and which is formed of the exoccipital, paroccipital, alisphenoid, mastoid, and postfrontal bones.

Occasionally the lower portion of the otocranes project below the true base of the skull, forming bony pouches, as may be seen in the Hemiramphus and some others.

The semicircular canals, as a general rule, are connected with one another in the following order:—The anterior with the posterior, and with the anterior termination of the external. The posterior, besides its union with the anterior, is joined to the posterior end of the external. At the points of union with the external, each canal terminates in an ampulla. In some cases the ampullæ are altogether wanting, and then each semicircular canal communicates with the vestibular sac by a separate tube; occasionally all the semicircular canals coalesce, and join the vestibular sac by one tubular prolongation. "The nerve supplying the ear-chamber and its contents arises between the fifth and the vagus," occasionally receiving fibres from each, and is distributed to the semicircular canals, ampullæ, and vestibular sac, directly over the otolites, a few delicate fibrillæ passing inwards to be spread over the otolites.

The acoustic purpose of this arrangement is rendered obvious by an experiment performed by Camper:—

"He filled a bag with water, and placed within it a small globular body which of course, from its unattached freedom, was capable of rolling in any direction, according to the force of an external impulse." "Sustaining the apparatus in one hand, he found that the slightest agitation given to the bladder was repeatedly felt by the reaction of the body within." "The vibration, then, of the hard masses existing in the ears of fishes, probably augment the intensity of hearing, not so much by reverberating from wall to wall in the labyrinthic cavity, as by direct propagation along the filaments of the auditory nerve attached to the surface of the vibrating body."

In a paper by Mr. Stoddart, "On the Organs of Hearing in the various classes of Animals," published in the 'Intellectual Observer,' is a statement that the three otolites are connected by a ligament traversing the groove in the under surface of the largest otolite. This ligament I have not succeeded in tracing, and am inclined to question its existence, from the fact that the superior otolite sometimes occupies a different position on the two sides of the head, as may be seen in two preparations from the same

Wolf fish. On the one side it is situated just below the junction of the anterior and posterior semicircular canals, and on the other side below the junction of the anterior and external.

Professor Müller says that sound is conveyed to the auditory organs of fish by three media in succession, viz.:—

1st. The water in which the fish lives.

2ndly. The solid parts of the body and of the organs of hearing.

3rdly. The fluid of the labyrinth.

There can be no doubt that these are the principal media by which sound is conveyed to the organ of hearing; still to these ought to be added the air-bladder (where it exists); for though no doubt the principal use of this organ is to enable the fish, by the generation or expulsion of its enclosed air, to rise or sink; yet it must materially assist in multiplying by resonance and conducting the vibrations to the auditory nerve, thus supplying the place of a tympanum, especially to those fish, such as the Cyprinidæ and Siluridæ, where a direct communication exists between the anterior air-bladder (by its tubular prolongation) and the chain of ossicles communicating with the otocrane and its contained otolites, semicircular canals, auditory nerve, &c.

This chain of ossicles has, by some comparative anatomists, been considered to be the representatives of the *ossicula auditûs* in other vertebrata. If they are recognized as such, we must deny to all fish, except those belonging to the highly favoured groups of Cyprinidæ and Siluridæ, possession of those organs of hearing. This subject, together with my reasons for questioning whether the opercular bones should, as believed by some, be considered the representatives of the *ossicula auditûs*, must form the subjects of future investigations.

Before passing on to the more immediate object of my paper, I would only add that I cannot understand the necessity of searching on the outside of the skull for these representatives, when we find the otocranes containing all the essentials.

The otolites, or ear-stones, by analysis are determined to consist principally of carbonate and phosphate of lime and mucus, with a very small proportion of animal matter.

Mr. Stoddart says, "They are evidently formed by the crystallization of *carbonate of lime* in a gelatinous fluid, a condition well known to every chemist as interfering with the proper crystalline angles and planes by altering the regular arrangement of the calcareous particles."

And in a subsequent paper he states that "otolites were de-

posited by a dialytic process, a thin section showing layer upon layer in strict accordance with such an origin."

Such is unquestionably the case with some of the Gadidæ, and may perchance be the character of the family; but in by far the largest number of fish the structure more nearly resembles that of bone.

The otolites amongst osseous fish may be said to be three in number on each side, as the exceptions to the rule are very rare. During the examination of more than 3700 fishes, I have only noticed five instances to the contrary. In three they were altogether wanting on one side, and normal on the other; these were in a Perch, Roach, and Salmon, fish possessing otolites sufficiently large to be readily found, if they existed. The fourth instance occurred in a Carp Bream (*Abramis brama*): the otolites on one side were quite normal in size, shape, and number; but on the other side *it* (for there was only one) was cartilaginous and abnormal. The fifth occurred in *Synaphobranchus Kaupii*, the anterior and posterior otolites being represented by numerous minute crystals imbedded in a tough membrane.

Though amongst my series of otolites a few examples of the three are exhibited, yet the only one of scientific interest is the central or largest, as the other two, which are usually placed superiorly and posteriorly, though occasionally lying on the central, or with it (as in the Cyprinidæ) forming a chain of bones, are in the majority of fish so small as to be with difficulty found, and, when found, of so little use for the purpose of scientific identification that I will almost pass over them, merely stating that the superior is usually more globose, smaller, and rather porcellanous, and varies considerably in form, being rounded, triangular, stellate, or hastate. The posterior otolite is usually semitransparent, somewhat resembling fish-bone in appearance, rounded, quadrate, semilunar, in one instance resembling the *stapes* wanting its base, and generally pectinated. Although many thousands of fossil otolites have been examined by me, no specimen that could be referred to either of the above has yet been met with.

The central or largest otolite is crystalline in structure, porcellanous, closely resembling beautifully pure enamel in appearance, very brittle, owing to the imperfect cohesion of its atoms, easily rubbing down into almost impalpable powder. In spirit the porcellanous appearance is after a time destroyed, and the otolites become, to a certain extent, chalky and opake. This otolite is concave above, convex and grooved below, indented or

denticulated at the margins, as a general rule wider anteriorly than posteriorly, though sometimes just the reverse—usually longer than broad, ovate, quadrate, pyriform, tapering at both ends, furcate at both ends, or furcate at one end and rounded at the other. In fact, to give anything like an idea of their protean forms, a description of almost every species would be necessary.

In the Sturionidæ, or Sturgeons, which are always arranged between the cartilaginous and osseous fish, the otolites, as might be expected, are of an intermediate type and distinct form, consisting of slightly adherent crystalline granules, imbedded in a dense cartilaginous membrane.

In the true cartilaginous fish the otolites are soft, shapeless masses, closely resembling wet chalk. Under a microscope they are seen to be composed of almost perfect rhombic crystals.

A good deal of stress has been laid on the shape of the "groove on the under surface of the central otolite, as absolutely necessary for the identification of a species." I am quite ready to admit that there is a very great difference in its shape amongst genera; but in closely allied species it is so similar as to be almost identical, and therefore, *per se*, not to be depended upon. So far as my experience goes, identity of outline is the only certain character: and fortunate it is that such is the case; for in by far the largest number of fossil otolites the convex under surface is more or less bouldered and consequently the shape of the groove altered, so that, were this essential for identification, but few species could be recognized. The concavity of the upper surface being better preserved, the task is rendered comparatively easy, and but little skill is necessary in dividing them into species. Without attempting to give a rigorous definition of what ought to constitute a species, I may remark in general terms that wherever I find fishes differing from each other to that degree and in those external characters which are usually accepted by naturalists as entitling them to rank as a distinct species, there I find each of these species having a distinct otolite, and with the distinction sufficiently well marked to enable me to refer each otolite, when detached, to the species of fish from which it has been taken—after having, of course, once seen it *in situ*. Now this is, perhaps, more than can be said of either teeth or scales, and certainly than can be stated of any other isolated portion of the skeleton or hard parts in fishes; and it is a generalization of the highest interest in connexion with palæontological researches, as these otolites are often met with in

tertiary formations when no other vestige of the fish to which they belonged has been preserved, all the other remains consisting of teeth and vertebræ of cartilaginous fish. It may be as well to state that, so far as my examinations of British fish have gone, every species, recognized as such by Mr. Couch, has its distinction borne out by the otolites.

Much diversity of opinion exists as to whether the otolites are to be looked upon as the "analogues" or "homologues" of the *ossicula auditûs*; but it appears to me that their position in the vestibular sac and semicircular canals proves that they are only excessive development of the otocones, and not representatives of the true ear-bones,—an opinion in which I believe most anatomists will concur.

In a short notice published some years since, I stated that the specific characters of the otolites were more to be depended upon than the generic. Further investigations induce me to considerably modify this assertion; and although every species may be recognized by its own peculiar central otolite, I am inclined to believe that it is possible to group the species of each genus as having some character in common.

Fossil otolites have long been known to all collectors of tertiary fossils, but no classification of them has yet been made. The first attempt was that of Mr. Charlesworth, nearly thirty years since, and engravings were made of some of the principal forms; but I believe nothing further has been done with them. The formations which have yielded them in the greatest abundance are the Crag (Coralline Crag), the Hordwell Highcliff, Bracklesham, Brook, and Bramshaw tertiary-beds, and the Gault of Folkestone.

All the otolites from the Coralline Crag, that I have yet had an opportunity of examining, belong, without a single exception, to existing species of Gadoids, viz. Cod, Whiting, Pollack, Whiting Pout, Green Cod, &c.; there is therefore every reason for believing that the portion of a skeleton of a fish from the Coralline Crag, described in the 'Geologist,' and with some hesitation referred to this family, was undoubtedly Gadoid.

Sufficient has been said, I think, to prove that, to the Palæontologist, the careful examination of these small bodies will be of great assistance in enabling him to trace to a comparatively remote era the first appearance of many of the existing species of fish.

To the student of recent ichthyology they will be found of equal value, enabling him to discriminate between closely allied forms. I speak with tolerable confidence of their specific value, having

examined more than 3700 fish, representing nearly 450 species, and never yet, save in the instance of the Carp Bream, found any abnormal form which could create a difficulty in identifying a species if ever seen before. In some closely allied species I must admit that the distinctive marks are very slight, but sufficiently characteristic to make their separation and identification a matter of no great difficulty.

1. In the Percidæ. The central otolite is more or less oblong (as in *Perca*, *Labrax*, and *Polyprion*); oval, posteriorly acuminate (as in *Acerina*, *Trachinus*, &c.).

2. In the Gurnards. Almost circular, with a slight furcation, margins indented.

In *Cotti*. Long and narrow, tapering at each end.

In *Gasterostei*. Smooth and rounded.

3. In the Sparidæ. Very concavo-convex, margins, especially the inner, deeply indented, tapering considerably at either end.

4. In the Scombridæ. Furcate (as in *Scomber* and *Caranx*); stellate (as in *Zeus*); irregularly pisiform (as in *Capros*).

5. In the Tænidæ. Elongated (as in *Sepola*); very deeply concave, the inner and outer margins bent inwards (as in *Trichiurus*).

6. In the Mugilidæ. Very concave, margins indented; width nearly equal.

7. In the Gobioidæ. Furcate (as in the Blennies and *Anarrhichas*); globular (as in the Gobies); elongated (as in *Callionymus*).

8. In the Lophiidæ. Outer margin semilunar, inner denticulated.

9. In the Cyprinidæ. Subglobular, cuneate posteriorly, the degree of cuneation being specific.

10. In the Esocidæ. Furcate, inner margin denticulated (as in *Esox*); elongate and oval (as in *Belone*, *Hemiramphus*, &c.).

11. In the Siluridæ. Subglobular and mammillated (as in *Callichthys*); pisiform (as in *Silurus*).

12. In the Salmonidæ. Rather triangular, anteriorly acuminate (as in *Salmo*); posteriorly furcate, denticulated below, and slightly acuminate anteriorly (as in *Coregonus*).

13. In the Clupeidæ. Posteriorly furcate and truncate, anteriorly rounded and indented.

14. In the Gadidæ. Thick, mammillated; pyriform, or elongate oviform (as in *Morrhua*); elongated and tapering (as in *Motella*).

15. In the Pleuronectidæ. Nearly flat, oval, rounded, quadrate or truncate.

16. In the Echeneidæ. Oval and furcate, deeply grooved.

17. In the Murænidæ. Oval (as in *Conger* and *Anguilla*); globular (as in *Leptocephalus*).

18. In the Anguillidæ. Elongate (as in *Ammodytes*).

19. In the Syngnathidæ. Globular.

20. In the Gymnodontidæ. Globular and very irregular (as in *Tetrodon*).

21. In the Sclerodermi. Irregular, posteriorly acuminate (as in *Balistes*).

Stray Notes on some of the smaller Crustaceans. Note II. On the Habits, &c. of the *Hyperiidæ*.

By THOMAS EDWARD, A.L.S.

[Read December 6, 1866.]

As intimated in my last, I would now speak more fully of the other three species alluded to, viz. *H. oblivia*, *medusarum*, and *minuta*.

Although I have, as already stated, occasionally taken both the others from the *Medusa*, I have never as yet met with, nor seen, even so much as a single specimen of either of these attached to anything. And of the first (*H. oblivia*) which seems to me to be the most abundant of the whole tribe, at least in this quarter, I have seen thousands, nay, millions, or countless hordes. So numerous are they occasionally, that I have seen the water to a certain extent darkened by them; and this was the case when not a single *Rhizostoma* was within view, or perhaps on the coast. And instead of the *Hyperia* assailing the fish, the latter would seem to have become the aggressors; for the stomachs of many of those that were caught about the periods referred to were generally well stored with these Crustaceans.

On one occasion, and in winter, immense shoals of the common Herring (*Clupea harengus*) chanced to visit us—a rather rare case; and great numbers were taken. About two dozen of these came into my household, and, as is my usual practice with all kinds of fresh fish, I of course looked into their stomachs to see what could be got there. On doing this I was rather surprised to find them all full of this Amphipod, as I had never before found them in the herring. This caused more to be procured, which were caught the day after, and I found their stomachs full also. From one I took 59, from another 47, and from a third 33; and all the others were more or less well crammed.

These statements are not on hearsay. They refer to undeniable facts which came under my own personal observation.